UC RIVERSIDE
School of Public Policy

UCR SPP Working Paper Series

February 2023 – WP#23-01

TABLE OF CONTENTS

ADVANCEMENTS TO THE RICARDIAN ANALYSIS IN THE PAST QUARTER OF THE CENTURY

Divya Prakash[1], Mehdi Nemati[2], Ariel Dinar[3*], Scott MacKenzie[4], Cory Struthers[5], Matthew S. Shugart[6]

[1]School of Public Policy, University of California Riverside, Email: dprak004@ucr.edu.
[2]School of Public Policy, University of California Riverside, Email: mehdin@ucr.edu.
[3]School of Public Policy, University of California Riverside, Email: adinar@ucr.edu.
[4]Department of Political Science, University of California, Davis, Email: samackenzie@ucdavis.edu.
[5]School of Public & International Affairs, University of Georgia, Atlanta, Email: Cory.Struthers@uga.edu.
[6]Department of Political Science, University of California, Davis, Email: msshugart@ucdavis.edu.
[*]Corresponding author

Summary:

This paper reviews the literature on the Ricardian analysis that has been used for estimating the net impact of climate change on agriculture and the value of adaptation. Surveying published research, we discuss revisions, expansions, and the criticisms researchers have made of the Ricardian analysis since its introduction by Mendelsohn, et al. (1994). The types of dependent variables and the choice of the climate variables utilized in the Ricardian analysis are synthesized and discussed. Additionally, our paper clarifies the distinctions between static and dynamic Ricardian analysis, farm types, and analyses employing aggregate and farm-level data. The paper summarizes the findings of previous studies at the study location and farm type level and also explores open questions and empirical concerns that require investigation in future research.

Acknowledgements: This paper is part of the research project "Private (On-Farm), Public, and Political Adaptation to Climate-Change-Induced Water Scarcity: Evidence from California," funded by USDA-NIFA (2022-67023-36381).

ADVANCEMENTS TO THE RICARDIAN ANALYSIS IN THE PAST QUARTER OF THE CENTURY

Divya Prakash[1], Mehdi Nemati[2], Ariel Dinar[3*], Scott MacKenzie[4], Cory Struthers[5], Matthew S. Shugart[6]

[1]School of Public Policy, University of California Riverside, Email: dprak004@ucr.edu.
[2]School of Public Policy, University of California Riverside, Email: mehdin@ucr.edu.
[3]School of Public Policy, University of California Riverside, Email: adinar@ucr.edu.
[4]Department of Political Science, University of California, Davis, Email: samackenzie@ucdavis.edu.
[5]School of Public & International Affairs, University of Georgia, Atlanta, Email: Cory.Struthers@uga.edu.
[6]Department of Political Science, University of California, Davis, Email: msshugart@ucdavis.edu.
[*]Corresponding author

Acknowledgment

This paper is part of the research project "Private (On-Farm), Public, and Political Adaptation to Climate-Change-Induced Water Scarcity: Evidence from California," funded by USDA-NIFA (2022-67023-36381).

ADVANCEMENTS TO THE RICARDIAN ANALYSIS IN THE PAST QUARTER OF THE CENTURY

Abstract

This paper reviews the literature on the Ricardian analysis that has been used for estimating the net impact of climate change on agriculture and the value of adaptation. Surveying published research, we discuss revisions, expansions, and the criticisms researchers have made of the Ricardian analysis since its introduction by Mendelsohn, et al. (1994). The types of dependent variables and the choice of the climate variables utilized in the Ricardian analysis are synthesized and discussed. Additionally, our paper clarifies the distinctions between static and dynamic Ricardian analysis, farm types, and analyses employing aggregate and farm-level data. The paper summarizes the findings of previous studies at the study location and farm type level and also explores open questions and empirical concerns that require investigation in future research.

Keywords: Ricardian analysis, structural Ricardian analysis, climate change impact, adaptation value, farmland values, net revenues

1. Introduction

Prior to 1994, crop-specific production function models were the most common approach for estimating the impacts of climate change on agricultural production and yields (Adams, et al., 1988). The impacts of single climate parameters were estimated by changing the level of one or several production input variables, such as temperature, precipitation, and carbon dioxide while keeping the rest unchanged. The results frequently forecasted significant yield losses due to global warming. Most of these studies calculated the impact of changing temperatures on farm yields and made little provision for adaptation (Adams, et al., 1990). Other studies permitted minor changes to irrigation water quantity, technology adjustments, or fertilizer application levels (Rosenzweig and Parry, 1994). None enabled the farmer to completely adapt to shifting climatic conditions (Adams, et al., 1990, Rosenzweig and Parry, 1994). This approach has a significant limitation since it overlooks the possibility that farmers would use adaptation strategies to deal with the adverse impacts of climate change. Therefore, estimates of climate change effects, using crop-specific analysis, potentially overestimated the damages due to climate change (Bozzola, et al., 2018). According to Mendelsohn, et al. (1994), the production function approach routinely overestimates production damage by leaving out the range of adjustments that farmers typically undertake in response to shifting economic or environmental situations. The authors emphasized the importance of adaptation actions in which new activities replace older, more sensitive, and less profitable activities due to changes in climate factors.

Mendelsohn, et al. (1994) introduced the Ricardian analysis, which intends to overcome the limitations of the production function approach and assign monetary values to farmer adaptation strategies. The Ricardian analysis assumes that farmland value captures future expected agricultural productivity. The method determines how much of the variations in land value can be attributed to climate factors while controlling for confounding hedonic variables such as soil quality and other local characteristics. The Ricardian analysis evaluates the direct impacts of climate change on farms and, thereby, the implicit effects of farmer adaptation. Each farmer has adapted to the environment where they live; thus, it implicitly captures adaptation by comparing the net outcomes of farmers' decisions in different climates (Sanghi and Mendelsohn, 2008, Weber and Hauer, 2003). The main feature of the Ricardian analysis is that it calculates the net benefits of all feasible adaptation alternatives to predict the long-run equilibrium consequences of climate change (Kolstad and Moore, 2020). Since the introduction of the Ricardian analysis, economists have been using this method to estimate the net economic impacts of climate change on the agricultural sector (e.g., Kurukulasuriya and Mendelsohn, 2008, Mendelsohn, et al., 2001, Schlenker, et al., 2005, Seo, et al., 2009).[1]

Since these early stages of Ricardian analyses, the method has had many modifications and expansions. The purpose of this paper is to review the literature on the use of the Ricardian analysis to estimate the net impact and the value of adaptation to climate change in agriculture.

2. Materials and Methods

First, we reviewed the work that cited Mendelsohn, et al. (1994) article, which was 2,649 articles. Furthermore, we performed a systematic literature review using the search terms "*Ricardian analysis*," “*Ricardian approach*,” “*Ricardian methodology*”, “*farmland values*,” “*net revenues*,” and “*climate change, agriculture, and adaptation*” in two databases (Google scholar and JSTOR), for publications analyzing the impact of climate change and agricultural adoption to climate change, using the Ricardian analysis. Finally, we reviewed works cited in the latest

---

[1] For the complete list of these papers, see Table A1 in the appendix.

relevant publications in the Ricardian analysis (DePaula, 2020, Gunaratne, 2022, Luh and Chang, 2021, Massetti and Mendelsohn, 2020, Nguyen and Scrimgeour, 2022, Nicita, et al., 2020, Ortiz-Bobea, 2020).

We began the search in May 2022 and finished the process in December 2022. We searched for articles without imposing restrictions on date or year, location, study design, study aim, or inclusion/exclusion criteria. Using the search procedure, we retrieved a pool of 2,836 records. From this initial pool, we excluded all records that did not pass the initial screening with titles and abstracts related to the Ricardian analysis. This further screening for papers with Ricardian analysis left us with 181 articles with titles and abstracts related to the Ricardian analysis. Based on this pool, we further screened the titles and abstracts using the following inclusion criteria: (1) written in English and (2) relevant to actually using the Ricardian analysis to study farmers' adoption of climate change and not only mentioning it as a reference to another method. We included both published articles as well as working papers such as World Bank Policy Research working papers. However, blogs, editorial comments and letters were excluded. We further reduced the dataset by eliminating works that were not relevant based on a full content review.

3. Results

Figure 1 describes the search process and the number of articles excluded in each step. For this study, we included 137 articles, of which 99 are actual empirical Ricardian analysis applications.

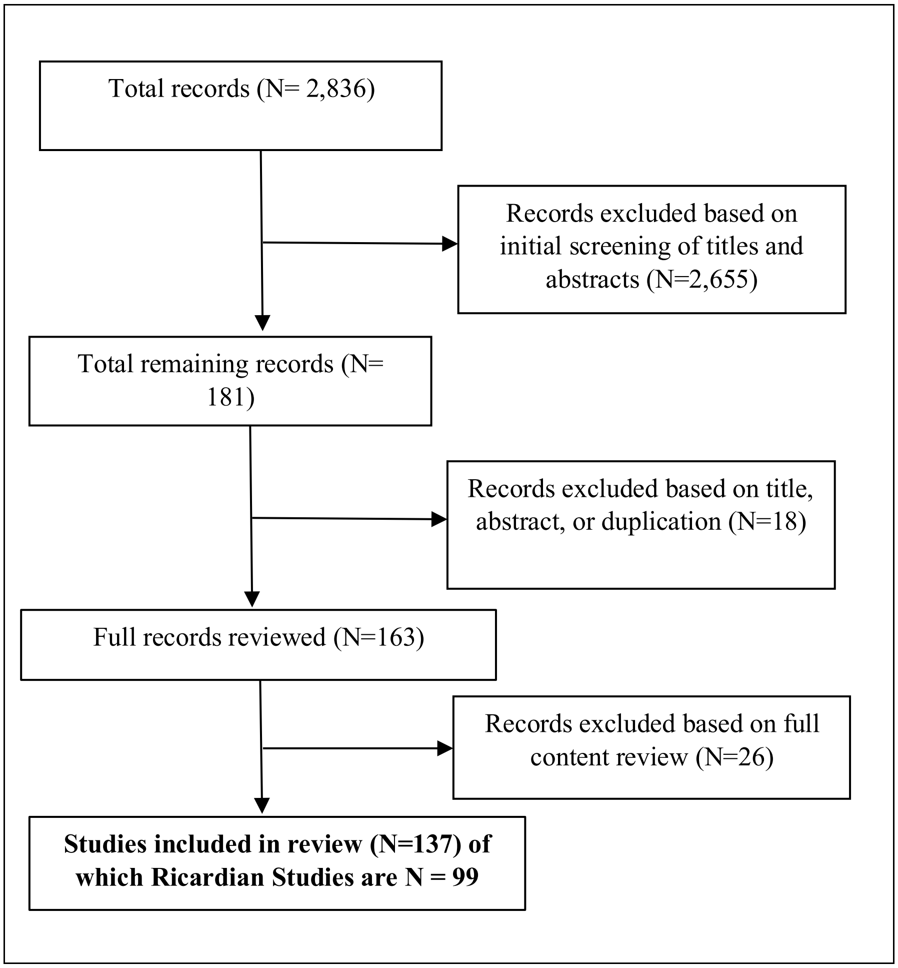

Figure 1. Studies screened and selected for inclusion in the review of the Ricardian analysis applications.

Appendix Table A1 provides the list of all identified published 99 articles that empirically study the Ricardian analysis along with information on the time of the study, location, model, data type, and type of dependent and independent variables, including climate variables.[2] As indicated in Table A1, out of 99 studies, 31 are from developed countries, 67 are from developing nations, and one is from both developed and developing countries.[3] Among

---

[2] Figure 1 corresponds to all the papers referred to for this study. The broad categories of included papers are (1) papers that study the Ricardian analysis empirically, (2) papers on the economic effects of climate change using crop-specific production function model, (3) papers on criticism of the Ricardian analysis and response, (4) papers on adaptation and distributional effects, and (5) papers that include important literature on the Ricardian analysis. Table A1 comprises only those studies that empirically study the Ricardian analysis.

[3] The distinction between developing and developed countries will be further discussed, but we should emphasize the difference in both farm size and structure, and difficulty at measuring some critical variables, such as land value.

developed countries, we observe that the majority of the studies are done in the US (15 studies), followed by Germany (7). Among developing countries, most of the studies are in African countries (35), followed by Brazil (6). In total, 31 studies used land value, 66 used net revenue, and two used land rents as dependent variables that measure the value of agricultural land. Most studies (93) utilized linear functional forms of dependent variables. We observed that each study included temperature and precipitation as climate variables, and a majority of those (94) used quadratic functional forms of climate variables followed by linear (3) and nonlinear (2) forms. A large number of studies have utilized farm-level data (86) compared to aggregate data at county, district or regional levels (12), and one used both farm-level and aggregate data.

Figure 2 presents the diffusion curve of the Ricardian studies between 1994 and 2022. It follows an S-shaped curve, as is the case of the diffusion of new technologies. There are broadly three phases in the diffusion process of the Ricardian studies. In the first phase (1994 to 2002), only a few Ricardian studies (<10% of the total) were published, corresponding to the initial public discourse about the Ricardian analysis and, therefore, a low incremental number of publications. In the second phase, between 2003 to 2011, there was a rapid increase in the number of publications which resulted in an increased marginal number of new studies, reaching an incremental increase of 40%. Finally, in the third phase (2012 to 2022), the marginal number of new Ricardian studies continues to increase but with a smaller but steady annual increase, resulting in a total of 50% of the additional publications. Interestingly, the stage of declining marginal increase has not been reached yet, so we expect still a significant increase in Ricardian studies in the next decade or so.

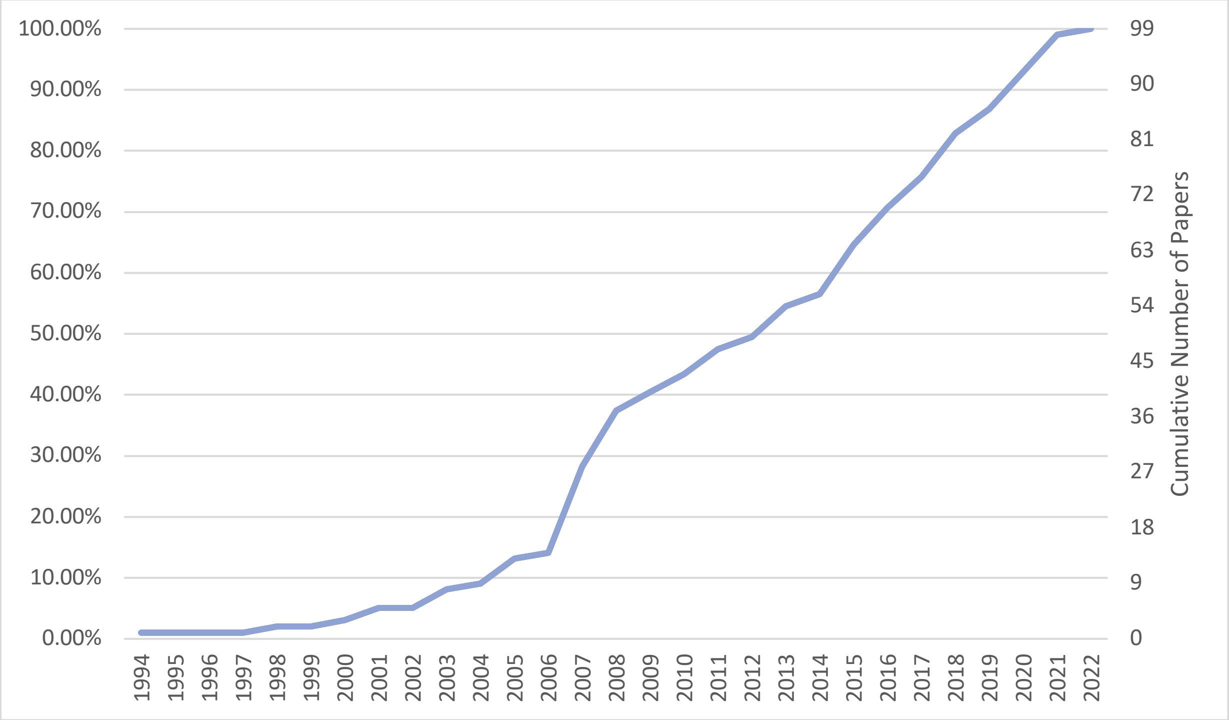

Figure 2. Diffusion Curve of Published Ricardian Studies since 1994 (Based on the data in Table A1)

In the following subsections (3.1-3.8), we describe the Ricardian studies across the following categories: dependent variables, climate variables, farm types, aggregate and farm level analysis, static vs. dynamic, multi-country and single country, study location, and farm types.

3.1 *Dependent variables*

There are two ways to perform a Ricardian analysis: the first utilizes the land value (Mendelsohn, et al., 1994); the second uses net revenue per year as the dependent variable (Dinar, et al., 1998). Land value or net revenue is used to calculate the net productivity of land for conditional income. The land valuation reflects the present value of each farm's net revenue over the long run. The land value measure is predicted to be a better measure since it reflects the expected value of net revenue. Generally, for all developed countries with active land markets, the dependent variable is farmland value per hectare. Farmland value includes the value of land and buildings. Schlenker, et al. (2005) suggest using a logarithmic transformation of farmland value as the dependent variable. Because farmland values have a log-normal distribution, it makes sense that the explanatory variables will have a proportionate rather than a linear impact on farmland value.

The lack of accurate measurements of the value of farmland due to non-existing or malfunctioning land markets is another significant barrier to using the Ricardian analysis in developing countries. Land ownership rights are not private in many cases and rather belong to the state. Since there are no land sales in these locations, land value cannot be quantified (Mendelsohn and Dinar, 2009). The Ricardian analysis can be modified by using net revenue per hectare in order to resolve this issue (Mendelsohn, et al., 2001). The net revenue is calculated by subtracting annual costs from annual gross revenue. The gross crop revenue per hectare is the sum of the quantities of yields of crops grown times their price divided by the cropland area. This number can represent the farm's average value rather than a precise measurement of value per unit of area for each plot. Net revenue has the advantage of excluding possible speculative elements of land value. Annual net revenue has the drawback of reflecting results only for one year at a time. However, reliance on net revenue can provide certain challenges.

Most farmers cultivate more than one crop annually, and some even have multiple cropping seasons or various plots, each dedicated to a different crop (Mendelsohn and Dinar, 2009). Another challenge is determining the appropriate crop prices because some farmers may sell their products to a buyer directly from their farm, while others may transport them to the market (Mendelsohn and Dinar, 2009). Another difficulty is that many farmers in developing countries employ the labor of their own families, thus creating difficulty in obtaining a trustworthy estimation of this type of cost because they do not pay themselves salaries (Seo and Mendelsohn, 2007). Moreover, farmers in these contexts may not always sell all their produce. Many farming households use a sizable portion of their produce for self-consumption (Seo and Mendelsohn, 2007).

3.2 *Accounting for climate variables*

Climate variables are incorporated among the regressors in the Ricardian analysis to model the climate change impact (Mendelsohn, et al., 1994). The linear and quadratic terms for temperature and precipitation are used to capture non-linearities in the response of farms to climate. As climate response is nonlinear, a quadratic functional form has been used for the climate variables. However, most commonly, most Ricardian analyses have used a linear or semi-log specification with a quadratic formulation for the climatic variables and a linear function for all control variables. A quadratic term of each climate variable captures a second-order approximation of the nonlinear shape.

In the Ricardian analysis, the monthly climatic normals (means over a long period) are used to represent climate change, which concerns long-term rather than short-term trends (Reinsborough, 2003). The official normals are calculated for a uniform 30-year period and consist of monthly or seasonal temperature and precipitation averages. A number of agronomic and Ricardian studies suggest that temperature and precipitation significantly impact farmland productivity, which varies across all four seasons (Mendelsohn, et al., 1994, Mendelsohn and Dinar, 2009). The non-growing season climate affects land value and is related to the growing season climate. Climate coefficients are biased when all seasons are not considered (Passel, et al., 2017). Hence it is recommended to incorporate all four seasons into the Ricardian analysis.

Several authors have modeled the monthly or seasonal averages of the temperature (Mendelsohn, et al., 1994, Seo, et al., 2009). A few authors have used the number of degree days instead of the monthly or seasonal average temperature (Deschênes and Greenstone, 2007, Schlenker, et al., 2005). The term "degree days" comes from the agronomic literature and refers to the fact that plant growth is linearly correlated with the temperature only within a defined range (Fezzi and Bateman, 2015). Because temperatures in different months might strongly correlate with one another, Schlenker, et al. (2005) demonstrate that the degree days approach is superior to including monthly averages. These decisions were criticized by Massetti, et al. (2014); they contended that average temperatures, rather than degree days, give a more realistic conclusion that seasons are crucial in illuminating the connections between climate regimes and economic performance. In 2016, Massetti, et al. (2016) showed that the four-season model offers more accurate out-of-sample forecasts than the growing season model employed by Schlenker, et al. (2005). Additionally, they demonstrated an almost perfect correlation between the average temperature from April to September and the degree days during this period.

The current level of precipitation significantly influences the impact of changes in precipitation. An increase in precipitation is quite beneficial in relatively dry areas. However, more precipitation is hazardous in areas that already experience quite high levels of precipitation and or humidity. Including additional climatic indicators, such as wind speed or sunlight, is also feasible. However, one must be cautious when using indicators that already reflect temperature and precipitation, such as evapotranspiration, to prevent duplicate counting and heteroskedasticity effects (Mendelsohn and Dinar, 2009).

The studies based on the aggregated unit of analysis (e.g., county-level observations rather than farm-level observations) have used interpolated climate data from nearby weather stations. Despite taking precise weather records throughout time, weather stations are not always situated close to farms (Mendelsohn and Dinar, 1999, Mendelsohn, et al., 2001). As a result, several studies looked at the potential of satellites to examine the measurements of both temperature and precipitation (Mendelsohn and Seo, 2007). Satellites offer more precise temperature measurements than data interpolated from weather stations. In contrast, precipitation cannot be directly measured by the available satellites (Mendelsohn et al., 2007). Soil moisture is the best indicator of precipitation; however, it did not perform as well as interpolated precipitation. The findings indicate that a combination of satellite temperature data and precipitation data from ground weather stations would provide the most accurate climate measurements (Mendelsohn, et al., 2007).

This section concludes that climatic variables are among the regressors in the Ricardian analysis to model the influence of climate change. Apart from the linear functional forms, quadratic functional forms of temperature and precipitation are also utilized to capture non-linearities in the climatic impact on farms. The monthly climatic normals are typically used to depict climate change. Several researchers have modeled the average monthly or seasonal temperature. The number of degree days rather than the monthly or seasonal average temperature has been employed by other researchers. The four-season model, however, provides more precise out-of-sample estimates than the growing season model. In addition, the most precise climate measures would come from a mix of satellite temperature data and precipitation data collected from terrestrial weather stations.

3.3 *Accounting for farm types*

The traditional Ricardian analysis measures the impact of climate change while accounting for adaptation. Still, the actual adaptations themselves are never explicitly assessed or identified (i.e., adaptation is taken as a black box). The "Structural Ricardian analysis " was developed to address this problem, which explicitly specifies adaptation measures and quantifies their influence on climate change impacts (Mendelsohn and Seo, 2007). This multi-stage approach estimates farm choices and then estimates the conditional income for each choice. The model uses cross-sectional data to assess how climate change affects expected revenue and the adaptive decisions made by farmers.

Seo and Mendelsohn (2008) utilized both traditional and structural Ricardian analysis to analyze the impact of climate change on livestock net revenues in Africa. The structural model was further improved by allowing the farmer to choose to convert to any one of the farm types: crop-only dryland farm, crop-only irrigated farm, mixed (both crops and livestock) rainfed farm, mixed irrigated farm, and livestock-only farm (Mendelsohn and Seo, 2007). Similarly, Kurukulasuriya and Mendelsohn (2008) used the structural Ricardian analysis to study the climate vulnerability of specific crops selected by African farmers. They looked at farmers' crop choices in various climates, assessing the influence of climate on these choices and estimating conditional net revenue functions for each crop. Massetti and Mendelsohn (2020) studied the temperature impact on mixed crop and livestock farms. To do so, they utilized only counties with mostly crop farms versus only counties with a mix of crop and livestock farms.

Kurukulasuriya and Mendelsohn (2008) used the structural Ricardian analysis to quantify how climate affects current net revenues for all farms in Africa, including dryland farms and irrigated farms. The study estimated a model of the choice of whether farmers adopt irrigation and then a model of their conditional income equation for irrigated and rainfed land. Similarly, Kurukulasuriya, et al. (2011) explicitly modeled irrigation choice as a function of climate. They proposed an endogenous irrigation model that takes sample selection bias into account. In the first step, the model calculated the likelihood of irrigation, considering the climate, district flows, and other exogenous variables. In the second step, the conditional revenue from rainfed and irrigated farms was estimated together with a sample selection adjustment term.

3.4 *Aggregate level and farm level analysis*

Farmland value is the fundamental economic variable used in the Ricardian analysis. The county-level data for the United States was used in the first applications of the Ricardian analysis (Mendelsohn, et al., 1994). The aggregate data is appealing because it is already available and gathered by agricultural census authorities in numerous nations. These values are self-reported estimations by each farmer as the government directs them to estimate the market value of their farms. These reported values include the value of both farms and buildings. The traditional county-level data is then constructed by aggregating this unique panel of farm-level data. Unfortunately, such information is scant in many places and frequently inconsistent.

To carry out the Ricardian analysis for nations without agricultural census data, gathering data on farms across climate zones is important. It is easy to conduct these surveys at the farm level. The collected data provides more specific information on farm activities and the revenue generated by each activity (Mendelsohn and Dinar, 2009). Work by Schlenker, et al. (2005) was one of the first to estimate the Ricardian analysis using farm-level data. One of the first studies in Africa that collected data from individual farmers to examine climate effects on farmland by estimating a Ricardian function. (Seo, et al., 2009) The analysis looked at net revenue from crops and livestock. The evaluations of individual farms have provided information about the areas of the world most sensitive to climate change. Most of the earlier research used either the county or regional-level data.

However, estimates of the effects of climate change derived from the farm- and county-level data differ (Fezzi and Bateman, 2015). Fezzi and Bateman (2015) suggest that aggregated data needs to accurately reflect the subtle variations in local climate that each farm in a county experiences.

3.5 *Static vs. dynamic analysis*

The Ricardian analysis is a comparative static analysis of long-run climate impacts, not a dynamic analysis of short-term weather effects (Mendelsohn and Dinar, 2009). The traditional Ricardian analysis, which Mendelsohn et al. (1994) proposed, has drawn criticism for being static. The Ricardian analysis uses single-year cross-sectional data to estimate the damage that climate change may cause to agriculture. Although the conventional model implies that prices are constant, they may change (Cline, 1996). Irrigation is a key factor that the model needs to completely account for to explain the differences in the farm earnings (Darwin, 1999, Schlenker, et al., 2005). It fails to account for the cost or the dynamics of changing equilibrium states (Kelly, et al., 2005, Quiggin and Horowitz, 1999). Farm decisions involving labor, capital, and crop selection are excluded from the Ricardian regression since they are endogenous (Mendelsohn and Dinar, 2009).

Multiple attempts have been made to overcome these problems and enhance the dynamic nature of the model. Mendelsohn and Dinar (1999) looked at the impact of climate variation. By including surface water and groundwater extractions as well as the adoption of advanced irrigation technologies, Mendelsohn and Dinar (2003) investigated the impact of water withdrawals and irrigation technologies. Schlenker, et al. (2005) looked at whether counties with rainfed farms responded similarly to other counties (e.g., irrigated farms). They included irrigation as an exogenous variable in their models. Kurukulasuriya and Mendelsohn (2007) improved the framework further by modeling irrigation as endogenous in nature. Rainfed and irrigated farms were separated by Kurukulasuriya and Mendelsohn (2007) and Seo (2008).

While the traditional Ricardian analysis measures impact, it also accounts for adaptability, which was never explicitly assessed or identified. The Structural Ricardian analysis was created to address this problem. The model specifically identifies adaption strategies and measures how much of an impact they have. The Structural Ricardian analysis has been investigated in several forms to study irrigation, crop, and livestock species selection (Kurukulasuriya and Mendelsohn, 2008, Kurukulasuriya and Mendelsohn, 2007, Seo and Mendelsohn, 2008). This strategy was also used to study the South American farm types (Mendelsohn and Seo, 2007) and the choice of farm types in the Africa (Seo, et al., 2009).

Instead of using seasonal temperatures during the growing season, Schlenker, et al. (2005) used degree days. These single-year studies do not produce consistent results over time, as shown by using the approach of repeated cross-sections (Deschênes and Greenstone, 2007). The latter suggested that to identify the consequences of climate change, one should concentrate on the intertemporal fluctuation in weather rather than a cross-sectional study. However, Massetti and Mendelsohn (2011) suggest that the cross-sectional variance is more relevant for determining the consequences of climate change than the intertemporal variation. They further added that if panel data is available, the then repeated cross-section is an incorrect strategy for estimating the results using the Ricardian method. Instead, panel data approaches should be used because they clearly define which coefficients should change over time and which ones should not.

To conclude, this section indicates that the traditional Ricardian analysis was static when it was first introduced in 1994. A number of researchers have continued to refine it over time to strengthen the dynamic nature of the model. The more detailed models included irrigation, water withdrawals, and irrigation technologies. Researchers separated rainfed and irrigated farms in the model and introduced the Structural Ricardian analysis to investigate various forms of adaptation. Researchers further recommended employing panel data, conditional on availability, instead of the repeated cross-section for predicting the results, using the Ricardian analysis, which further enhanced the model.

3.6 *Multi-country and single-country analysis*

Several studies have estimated multi-country Ricardian analyses for Europe (Passel, et al., 2017, Vaitkeviciute, et al., 2019, Vanschoenwinkel, et al., 2016), South-East Asia (Abidoye, et al., 2017), Asia (Mendelsohn, 2014), Africa (Kurukulasuriya, et al., 2011, Seo, 2008, Seo, et al., 2009) and Latin America (Mendelsohn and Seo, 2007, Seo, 2010, Seo, 2016, Seo and Mendelsohn, 2008, Seo and Mendelsohn, 2007, Seo and Mendelsohn, 2007). There are numerous single-country studies for the US (Massetti, et al., 2016, Ortiz-Bobea, 2020, Schlenker, et al., 2005), Europe (Bozzola, et al., 2018, Lang, 2007), Asia (Kumar and Parikh, 2001, Wang, et al., 2009), Africa (Jain, 2007, Kabubo-Mariara and Karanja, 2007) and Latin America (DePaula, 2020, Sanghi and Mendelsohn, 2008).

The multi-country research from Africa, Asia, and Latin America has shown that marginal changes in seasonal temperature and precipitation impact annual net revenues. The high uncertainty surrounding the climate estimations in these studies suggests that the climate sensitivities of each country are typically not statistically distinct from one another. The multi-country study from Europe shows that the climatic sensitivity of each European country varies. In southern European nations, higher marginal temperatures are detrimental, whereas, in northern European nations, they are advantageous. Except for the Scandinavian nations, most of Europe would benefit from a slight increase in precipitation (Passel, et al., 2017). Similarly, multi-country research of Brazil, India, and the US finds that each country has varied climate sensitivities. Brazil and India experience a more significant impact than the US (Sanghi and Mendelsohn, 2008).

The single-country studies have been performed in 54 countries, of which 20 are developed, and 34 are developing. Studies using the Ricardian analysis have found that temperature has similar positive marginal effects in Canada, Germany, Great Britain, and Israel (Fleischer, et al., 2008, Lang, 2007, Lippert, et al., 2009, Maddison, 2000), whereas results from Italy suggest that temperature has a negative effect (Bozzola, et al., 2018). While farms around the southern boundaries of the US are at risk, farmers in the northern area of the country may experience significant benefits. Additionally, the research predicts that Western US farmers will suffer (Massetti and Mendelsohn, 2011). The result of single-country studies from Bangladesh, Brazil, Cameroon, Egypt, Ethiopia, India, Kenya, Mexico, Myanmar, Nigeria, Pakistan, South Africa, Sri Lanka, Vietnam, Zambia, and Zimbabwe reveals that climate change has a marginally detrimental impact on net revenues. These results are consistent with those found in multi-country studies from developing regions.

3.7 ***Study location*****:** ***Developed versus developing countries***

To date, the Ricardian method has been applied worldwide across 54 countries from five continents (Figure 3). In total, we reviewed 137 studies, 55 in developed countries, 80 in developing, and 3 in both. Among developed countries, we observed that the majority of the studies were done in the US (25), followed by Italy (8), Germany (7), and Canada (3). Among developing countries, most of the studies were done in African countries (35) such as Burkina Faso, Cameroon, Ghana, Egypt, Ethiopia, Kenya, Mauritius, Niger, Nigeria, South Africa, Senegal, Togo, Zambia, and Zimbabwe. Then follow seven Latin American countries: (8) studies in Argentina, Brazil, Colombia, Chile, Ecuador, Uruguay, and Venezuela. Then China (5), India (4), Vietnam (4), Bangladesh (4), Sri Lanka (4), Nepal (2), Pakistan (2), and Thailand (2).

Figure 3. Map of countries with Ricardian studies reported in publications included in this review

The literature review suggests that the impact of climate change is unevenly distributed across developed and developing countries. This observation is supported by Mendelsohn et al., (2006), who modeled the distributional impact of climate change on rich and developing countries. A different study highlights that developed nations have better access to economic resources, infrastructure, and technology, so they are more likely to have stronger strategies for coping with climate change through mitigation and adaptation. In contrast, developing countries lack these resources and thus are more vulnerable to climate change (Wijaya, 2014).

The finding suggests that the impact of climate change is expected to be more severe in developing countries than in developed countries. Due to the current climate, damages are concentrated in developing countries. Developing nations are significantly hotter at present than usual because of their location in low-latitude regions, while developed countries in mid to high latitudes are currently cooler. As a result, damage from temperature increases is more significant in developing than in developed nations (Mendelsohn, et al., 2006). In general, developing countries would bear the damages associated with climate change. In contrast, developed countries will likely gain due to their global location and the improvements they will realize in their future climate.

In comparing the marginal effects of climate change on Canada and the US, a study found that while Canadian agriculture would benefit from additional precipitation, warmer temperatures have no effect. US farms benefit substantially less from increasing precipitation and are significantly more sensitive to warmer temperatures (Mendelsohn and Reinsborough, 2007). The climate change scale anticipated for the following decades will probably not have much of an impact on Canadian agriculture (Reinsborough, 2003). Climate change in California will likely result in lower farm profits, and various crops will be impacted differently (Deschenes and Kolstad, 2011). For the Southwestern United States, Dall'Erba and Domínguez (2016) found that the lowland counties are less susceptible to changes in the climate. In the highland areas, more frequent heat waves are also anticipated to have a negative impact on future land productivity. For the Southeastern United States, Quaye, et al. (2018) found that the regional farmland values increase with spring and fall temperatures and fall precipitation and decrease with winter and summer temperatures. Higher temperatures increase land values only if there is enough precipitation to prevent the risk of drought (Fezzi and Bateman, 2015). For Arkansas, Kovacs and Rider (2022) estimated that an inch drop in predicted rainfall during the growing season due to climate change increases the value of irrigated farmland per acre with an average saturated thickness of 120 feet. Depending on the agricultural land market, this value varies between $294 to $336 (US dollar).

Passel, et al. (2017) estimate that the marginal temperature rises from current levels in the spring and fall would improve the value of European farmland. In contrast, equivalent increases in the summer and winter would have the opposite effect. Increases in marginal precipitation in the spring and fall are detrimental, whereas such increases are beneficial in the winter and summer. The higher marginal temperatures are harmful in the southern European countries but are advantageous in northern European nations. Apart from the Scandinavian nations, most of Europe would benefit from a slight increase in precipitation.

According to Vaitkeviciute, et al. (2019), utilizing the single-growing season model (April – September) as opposed to a two-season model (April – June and July – September) may undervalue the significance of cold temperatures. They also discovered that both models accurately depict the effects of high temperatures. According to the estimation from the four-season model, the weather between October and March matters for Europe’s agricultural sector, with an optimum value of 18 °C. However, this temperature has not reached Europe during this period.

Bozzola, et al. (2018) found that land values in Italy are unaffected significantly by a uniform marginal increase in temperature throughout the year. Warmer summer temperatures are not beneficial, but warmer spring and fall temperatures are. In the North, increased yearly precipitation is significantly damaging, whereas, in the South and the Center, it is especially advantageous and vice-versa. In Germany, rising temperatures and falling spring precipitation will increase land rent, except for the eastern region (Lippert, et al., 2009). According to the findings, German farmers will benefit short-term from climate change. Global warming might result in losses over time. However, in the most likely scenarios, the net present value of climate change is positive (Lang, 2007). For England and Wales, Maddison (2000) discovered that the structural characteristics of farmland and the climate, soil quality, and elevation were the main predictors of farmland pricing in England and Wales.

Analyses of the land value and net revenue yield results that are quite comparable for Latin America. Using the Ricardian analysis, Seo (2016) found that an increase in rainfall has a minimal impact on land value, whereas an increase in temperature has a significant negative effect. However, by using spatial Ricardian analysis, he found that the impact of the temperature increase is less apparent. In contrast, the impact of the change in precipitation is similar to the Ricardian analysis.[4] Compared to high temperatures, farms with moderate temperatures earn more profit. Winter precipitation had no impact on the land value of small farms, whereas large farms located in areas with more winter precipitation had lower land values (Mendelsohn and Seo, 2007). The authors estimated that the value of agriculture in Mexico is climate-sensitive.

---

[4] A spatial Ricardian regression is run by incorporating the neighborhood effects. A random household is drawn from a defined neighborhood for the whole sample.

Warmer temperatures decrease the land value by USD 317 to 475 per degree Celsius (Mendelsohn, et al., 2010). In Brazil, the marginal effects of warming have become more negative, whereas the marginal effects of precipitation are less clear (Massetti, et al., 2013). The higher precipitation has a marginally negative influence on the land values of farms with low land quality. Similarly, the higher temperature negatively influences the land values of farms with moderate and high land-quality (DePaula, 2020).

The marginal warming in South-East Asia is estimated to be advantageous in the autumn but damaging in the summer. While an increase in autumn rains is detrimental, a slight rise in summer and especially winter precipitation is beneficial. Additionally, they observed that the net revenue from three-season farms would decrease. In contrast, the net revenue from one-season farms will increase due to climate change (Abidoye, et al., 2017, Abidoye, et al., 2017). In Bangladesh, the monsoon season's temperature has a negative marginal effect. In Vietnam, the temperature during the dry season is beneficial (Trinh, 2018). Rainfall during the monsoon season has a marginally detrimental impact on net revenues in Bangladesh and Vietnam. Rain during the dry season has a marginally favorable influence in Thailand and a slightly negative effect in Sri Lanka (Abidoye, et al., 2017).

In Bangladesh, Moniruzzaman (2015) found that crop choice is climate-sensitive and seasonal temperature has a more prominent effect on net revenues than seasonal precipitation (Hossain, et al., 2018). The marginal impact of rising temperatures will enhance net revenue during the summer cropping seasons (Hossain, et al., 2020). Additionally, the marginal effects of more significant precipitation increase net incomes for both crop seasons. On the other hand, the marginal effects of rising winter, summer, and fall temperatures are detrimental to agriculture in Vietnam, except for the rising spring temperatures, which are beneficial. While increased precipitation in the summer and autumn is anticipated to boost agriculture, increased precipitation in the winter and spring is projected to lower agricultural income (Nguyen and Scrimgeour, 2022). In Myanmar, Tun Oo, et al. (2020) observed that rising temperatures had a considerable negative marginal impact on households' net farm income. For both India and Brazil, the authors find that temperature changes have an adverse impact, whereas an increase in precipitation is beneficial (Mendelsohn, et al., 2001). The estimates show that warming would result in net revenue reductions of 7–17 percent in India and 10–30 percent loss in Brazil (Sanghi and Mendelsohn, 2008).

Mendelsohn (2014) estimated that consistent warming across China's four seasons will have an overall negative impact since the negative effects of spring and fall will outweigh the favorable benefits of winter and summer. Due to the predominately unfavorable results of spring and fall, the overall marginal impact of uniform warming is harmful in Asian countries, on average. In China, the average impact of higher temperatures is negative, and the average impact of more precipitation is positive. Overall, warming will be harmful to agriculture, and that negative impact will continue to grow over time. The study by Mendelsohn (2014) contrasts the finding of the study by Liu, et al. (2004), who found that warming will be beneficial (Wang, et al., 2009). In Tajikistan, rising temperatures and precipitation will both have a negative impact on agriculture and, as a result, on farmers' medium and long-term net revenue (Closset, et al., 2015). In Pakistan, increase in mean temperature considerably reduced net agricultural revenue per hectare on an overall basis (Sadiq, et al., 2019). Another study in Pakistan by Ali, et al. (2021) found that net revenue losses are highly correlated with annual average temperature increases and rainfall decreases. However, in Afghanistan, rise in the average annual temperature has a considerable positive impact on crop net revenue (Jawid, 2020). Similarly, in Nepal, the net farm revenue of the fall and spring seasons is positively impacted by low rainfall and high temperatures (Thapa and Joshi, 2010). Samrat and Alok (2017) found that increases in annual average temperature in Nepal had a net negative impact on farmland values, whereas increases in yearly average precipitation had a net positive impact.

Climate change also impacts agriculture in Africa. Kurukulasuriya, et al. (2006) found that increase in temperature for drylands crops and livestock results in a decline in revenue, whereas an increase in revenues for irrigated crops situated in a relatively cooler region. Nhemachena, et al. (2010) found that drier and warmer climates in Africa often have a negative impact on net farm revenues. Kurukulasuriya, et al. (2011) found that a slight rise in temperature along with more precipitation may be advantageous. However, a sharp rise in temperature without more rain will be quite damaging. Results in Seo, et al. (2009) indicate that climate variables are important determinants of farm net revenues in Africa. A small increase in temperature would harm net agricultural revenues in Africa. A small increase in precipitation would harm farmers according to the country fixed effects model but help them according to the OLS model. The country dummies are present in the fixed effects version of this model but not in the OLS version. The study concluded that the impacts of climate change would not be evenly distributed across Africa. According to Gbetibouo and Hassan (2005) estimates from 2005, a rise in temperature in South Africa positively impacts net revenue, while a decline in rainfall has a negative impact.

In Kenya, extreme summer temperatures decline net crop revenue but increase winter temperatures, whereas precipitation boosts net crop revenue (Kabubo-Mariara and Karanja, 2007). Similarly, rising temperatures and decreasing precipitation for Ethiopian agriculture reduce net farm revenue (Deressa, 2007). Zimbabwe’s net farm revenues are affected negatively by temperature increases and positively by precipitation increases (Mano and Nhemachena, 2007); similar results were found for Cameroon and Egypt (Eid, et al., 2007, Molua, 2007). In Zambia, rising mean temperatures in November and December and falling mean rainfall reduces net farm income. In contrast, rising mean temperatures in January and February and rising mean annual runoff are beneficial (Jain, 2007). In Niger, the rising temperature has a negative effect, while increases in rainfall positively affect crop net revenue (Bello and Maman, 2015). In Nigeria, it found that the marginal impact of temperature and precipitation varies according to the season and the agro-ecological zones (AEZs) (Coster and Adeoti, 2015, Onyekuru and Marchant, 2016). In Nigeria, rising temperature and decreasing precipitation is expected to affect the net farm income of rice producers (Ojo and Baiyegunhi, 2021). In Togo, high precipitation during the rainy season is likely to increase net farm income (Mikémina, 2013). In Mauritius, Sultan (2021) discovered that fluctuations in mean summer temperature and precipitation have a negative impact on the agriculture sector and that net farm revenue is more susceptible to temperature than precipitation.

In summary, this section can be broadly classified into three categories, namely, variations (1) between countries, (2) within countries, and (3) across various seasons. In comparing the variations across countries, it is discovered that higher marginal temperatures are favorable in northern European countries but damaging in southern European countries. A slight increase in precipitation would also benefit most of Europe, except the Scandinavian countries. It has been discovered that even a marginal rise in temperature will harm net agricultural revenue throughout developing countries. While comparing the variations within countries, it is discovered that the rising temperatures in California will probably lead to lower farm profits for the United States. However, the lowland counties in the Southeast region of the USA are less vulnerable. The regional farmland values rise in the Southwest region with spring and fall temperatures along with fall precipitation, whereas farmland values decrease with winter and summer temperatures. On comparing the variations across seasons, it is found that the marginal rise in temperature from current levels in the spring and fall would raise the farmland value for developed countries. In contrast, equivalent increases in the summer and winter would have the opposite effect. Extreme summer temperatures in Africa reduce net crop revenue, while increasing winter temperatures and precipitation increases net crop revenue. In South-East Asia, marginal warming will be beneficial in the fall but harmful in the summer.

3.8 *Farm types*

Previous research indicates that different farm types, such as crops, livestock, irrigated farms, and rainfed farms, may all respond to the change in climate in different ways (Bozzola, et al., 2018, Chatzopoulos and Lippert, 2015, Kurukulasuriya, et al., 2011, Passel, et al., 2017). In the United States, high temperatures slightly impact crop and mixed (crop and livestock) farms. In contrast to mixed farms, the values of crop farms farmland are more responsive to rising temperatures. Farmers who frequently experience high temperatures have opted to raise livestock rather than cultivate crops. For both crop and mixed farms, cold weather increases the value of farmland (Massetti and Mendelsohn, 2020).

The temperature effects on crops and livestock farms follow a similar pattern in Europe (Bozzola, et al., 2018, Passel, et al., 2017). Crop farmland value often experiences more significant seasonal temperature effects than livestock farms for all seasons except spring. Crop farms benefit substantially more from warmer autumns (Bozzola, et al., 2018). On the contrary, warming in the spring is more advantageous for livestock than crop farms (Passel, et al., 2017).

There is usually a little difference between crop and livestock farms in how a slight variation in precipitation affects them.

According to a study by Seo and Mendelsohn (2008), climate significantly impacts net livestock income in Africa. As a result, small farms experience an increase in livestock income as the temperature rises, while large farms see a decline in income. Rainfall lowers the net revenue from livestock. They also found that when it gets warmer, net farm revenues from crop-only and livestock-only farms decline while net farm revenues from mixed farms rise (Seo and Mendelsohn, 2008). In Africa, small-scale mixed crops and livestock systems are most resilient to climate change and reduced rainfall (Nhemachena, et al., 2010). In China, the long-term temperature reduces the net revenue from livestock, whereas long-term precipitation increases the same (Feng, et al., 2021). A study by Batsuuri and Wang (2017) predicts that, in Mongolia, increasing temperatures will decrease earnings per livestock, and more significant climate changes will lead to reduced household earnings. These studies starkly contrast the study by Adams, et al. (1999) about the climate sensitivity of livestock in the US, which states that US livestock is not climate sensitive. This difference likely arises because the former study is in a developing country compared to the latter study, which is in a developed country and hence has access to more economic resources (e.g., technologies, know-how) to protect livestock from extremely hot temperatures.

The irrigated and rainfed crop fields have various climate sensitivities. Bozzola, et al. (2018) estimated that increased yearly temperatures are favorable for rainfed land but detrimental for irrigated farms in Italy. However, the value of irrigated and rainfed farms is unaffected by a marginal change in annual precipitation (Bozzola, et al., 2018). In Europe, a marginal warming increase results in the rise of irrigated farmland value somewhat more than rainfed farms on average. Irrigated farms, on the contrary, benefit significantly from a marginal increase in precipitation, while rainfed farms gain slightly (Passel, et al., 2017). The net revenues of irrigated farms are unquestionably more susceptible to precipitation than those of rainfed farms, even after controlling for the climate (Passel, et al., 2017).

In the African region, irrigated and rainfed farms do not respond to temperature in a similar pattern (Kurukulasuriya, et al., 2011). Higher temperatures tend to cause net revenues from rainfed farms to decline. In contrast, net revenues from irrigated plots are less impacted. Outside areas with significant rainfall, rainfed and irrigated fields seem to respond well to greater precipitation levels (Kurukulasuriya, et al., 2011). For Africa, Seo (2008) discovered that as precipitation increases, farm net revenues from irrigated farms decrease while net farm revenues from rainfed farms rise. Farmers are prompted to alter their preferred farm type by these variations in net revenues. In South Africa, irrigated farms are anticipated to have net revenues that are relatively higher than dryland farms. Also, large farms are expected to have net revenues that are much higher than small farms (Benhin, 2008). Ajetomobi, et al. (2011) found that in Nigeria, for dryland rice farms, an increase in temperature will result in a decrease in net revenue; however, for irrigated rice farms, net revenue will increase as the temperature rises. Similarly, rainfall had equivalent impacts on rice's net revenue. In Ghana, Bawayelaazaa Nyuor, et al. (2016) found that high temperature and rainfall in summer are expected to decrease net revenue of rain-fed farms. In Nigeria, Fonta, et al. (2018) found that increases in average annual temperature and declines in precipitation are linked to net revenue per hectare losses for rainfed farms and gains for supplemental irrigated.

China’s irrigated farmers benefit from warming because they can utilize water to counteract the heat. Contrarily, rainfed farmers are particularly vulnerable to warming and will experience declines in their net income (Wang, et al., 2009). In Bangladesh, farms located in locations with adequate irrigation systems saw a favorable impact of temperature rise on net crop income (Hossain, et al., 2018). Rainfed fields and irrigated farms respond to the climate differently throughout Latin America (Mendelsohn and Seo, 2007). In Mexico, rainfed farms will sustain slightly more losses as a percentage of income than irrigated farms, but comparisons between small and large farms are mixed (Mendelsohn, et al., 2010). In Mexico, the net revenue per hectare will be expected to reduce with an increase in temperature of 2.5°C and a 10 percent reduction in precipitation for all farm types. The average net revenue losses will range for irrigated between 26 to 55%, 14 to 25% for rainfed and 27 to 37% for mixed municipalities (Luis, et al., 2015).

In summary, this section suggests that climate change has a marginal impact on developed countries' farm types, such as crops, livestock, and mixed farms. On the contrary, these farm types in developing countries are significantly affected, particularly the larger farms. A marginal increase in temperature in developed countries increases the average value of irrigated farmland more than for rainfed farms. On the other hand, rainfed farms only gain marginally from a minor increase in precipitation, but irrigated farms benefit considerably. Rainfed farms and irrigated farms react to the climate differently in developing nations. Rainfed farms would relatively experience more reduction in net revenue as a result of warming since they are more susceptible to it.

4. Criticism and Methodological Improvements to the Ricardian Analysis

Since its introduction, the Ricardian analysis has been the subject of several critiques, such as the presence of omitted variable bias, the implicit assumption of fixed prices, and the potential for spatial aggregation bias. The model's partial equilibrium method assumes fixed prices and was criticized by Cline (1996), who argued that the model would overstate the benefits of climate change and underestimate its harmful effects. This method does not take into account prices of different commodities changing with shifts in entire production. Additionally, the Ricardian method ignores the frictional costs associated with switching from one production system to another. Another shortcoming is that it ignores variables that are constant with regard to space, like the carbon fertilization effect (Cline, 1996). Although it is easier to critique this research for presuming constant pricing, it is challenging to account for price impacts in any approach as, most of the time, a global market determines prices (Mendelsohn and Dinar, 1999).

The comparative static nature of the Ricardian analysis is a further, crucial criticism (Quiggin and Horowitz, 1999). These authors argued that rather than looking at changes in climatic variables at a single level, the effects of climate change on agriculture should be examined dynamically. The dynamics of transitioning from one climate regime to another are disregarded. They also highlighted that the Ricardian analysis assumes costless market-based adaptation to climate change. However, switching crops is not costless (Quiggin and Horowitz, 1999): The purchase of new harvesting equipment, the construction of irrigation infrastructure, and the development of technological know-how could be included in the fixed costs of moving from one crop to another. Therefore, depending on how expensive it is for farmers to transition from one crop to the next, this method may produce biased estimates of the impact of climate change (Auffhammer, 2018).

Several studies have questioned the absence of an irrigation system (Cline, 1996, Darwin, 1999), as it may result in an inaccurate calculation of the signs and magnitude of climatic variables (Fisher and Hanemann, 1998). Climate variables, like average temperature, are spatially associated with other variables, like soil types, distance to cities, and irrigation systems. The climate variables may pick up the impacts of variables other than climate and result in inaccurate estimates and predictions if important variables that are connected with climate are not included in the regression model (Schlenker, et al., 2005). It disregards aspects that depend on both time and place, such as the quality of soil and farmers' unobservable abilities (Di Falco, 2014). To address these criticisms, Mendelsohn and Nordhaus (1999) modified the hedonic Ricardian function and accounted for irrigation's impact in the constant term. The other estimated coefficients, particularly those pertaining to climatic factors, were not, however, taken into consideration by the modified model. Additionally, it was argued that the Ricardian analysis ignores the cost of transition (Kelly, et al., 2005). The analysis does not measure short-run transition costs but rather long-term equilibrium consequences (Mendelsohn and Dinar, 2009). Since these early stages of the Ricardian analysis work, there have been many modifications and expansions to the method.

Over time, several studies have suggested methodological improvements to address some of these issues. Mendelsohn and Dinar (2003) examined how irrigation helps American agriculture adapt to climate change. They incorporated variables for assessing surface water withdrawals and the adoption of improved irrigation technologies and discovered that surface water withdrawals raise farm values. Omitting this variable in the Ricardian analysis could lead to underestimating the benefits of warming. The groundwater withdrawals were found insignificant as they are endogenous and already captured by the models. They also discovered that the climatic sensitivity of irrigated farms and rainfed farms differ. Irrigated farms are more beneficial in regions with higher temperatures and less precipitation than rain-fed farms. Schlenker, et al. (2005) highlighted that irrigation is a significant factor in farm profitability. They considered irrigation as an exogenous variable and studied its exclusion in the Ricardian method by estimating separate regressions for rainfed and irrigated lands. They concluded that the economic effects of climate change on agriculture need to be assessed using different variables for dry land and irrigated areas in the model specification.

In the context of a Ricardian analysis, Kurukulasuriya and Mendelsohn (2007) developed a choice irrigation model in which they treated irrigation as an endogenous variable. In the first step, they examined how climate affects the decision to employ irrigation. In the second step, they measured the impact of climate on the net revenues of dryland and irrigated land. The Ricardian analysis must account for the availability of water sources from outside the county (or farm, depending on the unit of observation), even if it is unclear whether irrigation must be explicitly included. The coefficients on climate in the Ricardian analysis can change if external water sources are included. Studies using the Ricardian analysis that do not account for external water sources may be biased (Mendelsohn and Dinar, 2009). Benhin (2008) provided a somewhat different perspective by using the revised Ricardian analysis to evaluate how climate change will affect crop production in South Africa. The author included hydrological factors, such as river flow and water availability, which are disproportionately impacted by climate change.

Instead of performing multiple cross-sectional analyses, Massetti and Mendelsohn (2011) suggested using the panel data method to estimate Ricardian analysis. Because the coefficients of time-varying and time-invariant variables are permitted to vary over time in the repeated cross-sections, the results are not robust and are mis-specified. On the contrary, climate coefficients using panel data methods are significantly more accurate. By contrasting the results obtained from a unique panel of farm-level data with traditional models calculated on data averaged over counties, Fezzi and Bateman (2015) checked for spatial aggregation bias. They discovered that climatic coefficients suffer from a significant bias based on aggregated data. Kumar (2011) studied the spatial autocorrelation of error terms. He discovered a sizable positive spatial autocorrelation that accounting for this can improve the accuracy of climate impact studies.

Burke and Emerick (2016) develop a long differences approach and use the difference between panel estimates and long differences estimates to quantify agricultural adaptation. Severen, et al. (2018) suggest that the typical Ricardian analysis overestimates the influence of climate on land values when land values already capture information on climate change. They propose a new “forward-looking” Ricardian analysis that considers market perceptions of climate change. Vanschoenwinkel and Van Passel (2018) suggest that it is imperative to clearly define irrigated agriculture rather than simply assuming that all types of irrigated farms are same. Instead of using farmland values, Ortiz-Bobea (2020) recommends using cash rental data to lessen the impact of non-farm omitted factors. Nicita, et al. (2020) developed a structural Ricardian analysis that considers endogenous farm-type selection. They considered spatial effects and estimated a Ricardian spatial Durbin (SD) model. Both a geographically lagged dependent variable and a spatially lagged independent variable are present in this model. They found that Ricardian analysis should not ignore spatial correlation and adaptability because they significantly impact assessing consequences and are endogenous in nature.

5. Discussion

The detailed review of the research papers indicates that the impact of climate change is not uniform across the globe. The economic impact due to climate change is more substantial in developing countries than in developed countries. The effect is quite different even for the countries falling under the same geographical region. Overall, for developed countries (most of which are in the northern hemisphere), the marginal increase in temperature has a significant positive impact on the value of the farmland. For a few countries, such as Canada, warmer temperatures have no effect. In general, warmer spring and fall are more beneficial than summer. Similarly, the marginal increase in precipitation increases the farmland value in the summer and winter seasons. On the contrary, developing countries are extremely climate sensitive. In general, the marginal impact of rising temperatures has become more detrimental, harming the net agricultural revenues. However, the effects of climate change are not evenly distributed across different countries and seasons.

Different farm types in developed and developing countries respond differently to climate change. In developed countries, an increase in temperature has a marginal impact on crop and mixed crop-livestock farms but a more significant positive impact on livestock farms. Farmers move away from crop farms to livestock farms in warm temperatures. In contrast, it increases the farmland value of crops and mixed farms in cold weather. Precipitation has a marginal impact on all different farms. In contrast, a significant effect on net income from different farm types is estimated for developing countries. Higher temperature increases the net revenues for livestock farms of only small farms. Farmers' net revenues from mixed farms increase when it gets warmer, whereas rainfall reduces the net revenues of livestock farms.

In developed countries, an increment in temperature is beneficial for rainfed farms but harmful for irrigated farms. At the same time, increased precipitation results in a decline in the farmland value of rainfed farms and an increase in farmland revenue for irrigated farms. In contrast, for developing countries, an increase in temperature results in a decline in net revenue from rainfed farms, and an increase in precipitation results in a reduction in net revenue from irrigated farms and an increase in net revenues from rainfed farms.

6. Conclusion

Mendelsohn, et al. (1994) first described the Ricardian analysis in their original work. The approach has been popular and widely employed applied econometric techniques for researching the economic impact of climate change. However, it has been criticized frequently for several estimation challenges, and significant issues related to its accuracy were brought up. Still, the Ricardian analysis is appealing since it is relatively simple to estimate, provides an upper bound on the benefits of climate change, accounts for the adaptation (Reinsborough, 2003), and is convenient to interpret.

Researchers have acknowledged the importance of this approach for the past 28 years. They have expanded its use to overcome its main drawbacks, including adding irrigation as an endogenous variable in the model, taking care of the endogeneity issue, addressing the implicit consideration of adaptation measures, dealing with the timing instability of the Ricardian climate coefficients, the use of panel data models, the issue of aggregation bias, spatial correlation treatment, and taking into account consumer perceptions of climate change. They have also expanded the model's application beyond county-level to individual-level farm data.

Researchers have evaluated several functional forms of dependent variables (farmland value or net revenues), including linear, quadratic, Box-Cox, simple spatial error models, spatial fixed-effect and spatial Durbin models, as well as diverse functional forms of climatic variables, including linear, nonlinear, and quadratic forms. Finally, numerous works show that this approach may be applied to small and large farms, as well as to many farm types, including those that are irrigated, rainfed, or that raise crops, livestock, and mixed crop-livestock farms. As a result, the adoption of this method has thus grown, even though some critical problems, including the capture of future technologies, future changes in crop varieties and animal breeds, investments, spatial aggregation bias, and changing prices as opposed to the illicit assumption of fixed prices, remain unresolved.

Still, the Ricardian analysis needs to examine how adaptation is applied. Other concerns are still debated, such as the ideal variable to represent climate change, degree days versus normal (30 years) climate, and monthly versus seasonal climate. To conclude, the Ricardian analysis has significantly advanced over the past 28 years, but many vital problems still need to be resolved.

Appendix

Table A1. Overview of the peer-reviewed studies on the Ricardian analysis.

Name of Authors	Location	Model[5]	Level of Analysis	Dependent Variables	Climate Variables	Non-Climate Variables	Functional form: Dependent Variables	Functional form: Climate Variables
Mendelsohn, et al. (1994)	US	Ricardian	Aggregate	Net Revenue	Temperature Precipitation	Soil, topography and socioeconomic	Linear	Quadratic
Sanghi, et al. (1998)	India	Ricardian	Aggregate	Net Revenue	Temperature Precipitation	Soil and socioeconomic	Linear	Quadratic
Maddison (2000)	Wales and the United Kingdom	Ricardian	Farm	Land Value	Temperature Precipitation Wind Speed Foggy Days	Soil and socioeconomic	Linear	Linear
Kumar and Parikh (2001)	India	Ricardian	Aggregate	Net Revenue	Temperature Precipitation	Soil, topography and socioeconomic	Linear	Quadratic
Mendelsohn, et al. (2001)	India, Brazil, and US	Ricardian	Aggregate	Net Revenue and Property Value	Temperature Precipitation	Soil and socioeconomic	Semi-log quadratic	Quadratic
Mendelsohn and Dinar (2003)	US	Ricardian	Farm	Land Value	Temperature Precipitation	Soil, hydrology	Linear	Quadratic

---

[5] The "structural Ricardian analysis " is a multi-stage model that calculates farm choices first, followed by estimates of the conditional income for each choice. The model uses cross-sectional data to assess how climate change affects predicted revenue as well as the adaptive decisions made by farmers. In comparison, the standard Ricardian analysis does not shed light on how farmers adjust to climate because adaptation is treated endogenously.

						and socioeconomic		
Reinsborough (2003)	Canada	Ricardian	Farm	Land Value	Temperature Precipitation	Soil and socioeconomic	Linear	Quadratic
Weber and Hauer (2003)	Canada	Ricardian	Farm	Land Value	Temperature Precipitation	Soil and socioeconomic	Linear	Nonlinear
Liu, et al. (2004)	China	Ricardian	Aggregate	Net Revenue	Temperature Precipitation	Soil, socioeconomic and topography	Linear	Quadratic
Deressa, et al. (2005)	South Africa	Ricardian	Aggregate	Net Revenue	Temperature Precipitation	Soil, socioeconomic and topography	Linear	Quadratic
Gbetibouo and Hassan (2005)	South Africa	Ricardian	Aggregate	Net Revenue	Temperature Precipitation	Soil and socioeconomic	Linear	Quadratic
Schlenker, et al. (2005)	US	Ricardian	Farm	Land Value	Degree days Precipitation	Socioeconomic and soil	Linear	Quadratic
Seo, et al. (2005)	Sri Lanka	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, socioeconomic and topography	Linear	Quadratic
Kurukulasuriya, et al. (2006)	Africa	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, socioeconomic and topography	Linear	Quadratic
Deressa (2007)	Ethiopia	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil and household	Linear	Quadratic
Deschênes and Greenstone (2007)	US	Fixed effect	Aggregate	Net Revenue	Degree days Precipitation	Socioeconomic and soil	Linear	Quadratic

Eid, et al. (2007)	Egypt	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, socioeconomic, hydrology and technology	Linear	Quadratic
Jain (2007)	Zambia	Ricardian	Farm	Net Revenue	Temperature Humidity	Soil, socioeconomic and hydrology	Linear	Quadratic
Kabubo-Mariara and Karanja (2007)	Kenya	Ricardian	Farm	Net Revenue	Temperature Precipitation	Socioeconomic and soil	Linear	Quadratic
Kurukulasuriya and Ajwad (2007)	Sri Lanka	Ricardian	Farm	Net Revenue	Temperature Precipitation	Socioeconomic and soil	Linear	Quadratic
Kurukulasuriya (2007)	Africa	Standard Ricardian	Farm	Net Revenue	Temperature Precipitation	Socioeconomic and soil	Linear	Quadratic
Kurukulasuriya and Mendelsohn (2007)	Africa	Standard Ricardian	Farm	Net Revenue	Temperature Precipitation	Socioeconomic and soil	Linear	Quadratic
Lang (2007)	Germany	Structural Ricardian	Farm	Land Value	Temperature Precipitation	Topography, economic environment and profits	Quadratic Box–Cox	Nonlinear
Mano and Nhemachena (2007)	Zimbabwe	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, socioeconomic and hydrology	Linear	Quadratic
Mendelsohn and Reinsborough (2007)	Canada	Ricardian	Farm	Land Value	Temperature Precipitation	Socioeconomic and topography	Linear	Quadratic

Molua (2007)	Cameroon	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, water flow and socioeconomic	Linear	Quadratic
Seo and Mendelsohn (2007)	Latin America	Structural Ricardian	Aggregate	Net Revenue Land Value	Temperature Precipitation	Socioeconomic and soil	Linear	Quadratic
Seo and Mendelsohn (2007)	Africa	Structural Ricardian	Farm	Net Revenue	Temperature Precipitation	Socioeconomic	Linear	Quadratic
Fleischer, et al. (2008)	Israel	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, socioeconomic, hydrology and topography	Linear	Quadratic
Kabubo-mariara (2008)	Kenya	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, socioeconomic and hydrology	Linear	Quadratic
Kurukulasuriya and Mendelsohn (2008)	Africa	Structural Ricardian	Farm	Net Revenue	Temperature Precipitation	Topography and water flow	Linear	Quadratic
Sanghi and Mendelsohn (2008)	Brazil and India	Ricardian	Aggregate	Net Revenue	Temperature Precipitation	Soil, socioeconomic and topography	Linear	Quadratic
Seo (2008)	Africa	Structural Ricardian	Farm	Net Revenue	Temperature Precipitation	Socioeconomic	Linear	Quadratic
Seo and Mendelsohn (2008)	Africa	Structural Ricardian	Farm	Net Revenue	Temperature Precipitation	Socioeconomic	Linear	Quadratic
Seo and Mendelsohn (2008)	Africa	Structural Ricardian	Farm	Net Revenue	Temperature Precipitation	Socioeconomic	Linear	Quadratic
Seo, et al. (2008)	Africa	Ricardian	Aggregate	Net Revenue	Temperature Precipitation	Socioeconomic	Linear	Quadratic

Benhin (2008)	South Africa	Standard Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil and hydrology	Linear	Quadratic
Seo, et al. (2009)	Africa	Ricardian Fixed effect	Farm	Net Revenue	Temperature Precipitation	Soil, hydrology and topography	Linear	Quadratic
Lippert, et al. (2009)	Germany	Structural Ricardian	Farm	Land Value	Temperature Precipitation	Soil and grassland share	Simple spatial error model	Linear
Wang, et al. (2009)	China	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, socioeconomic and topography	Linear	Quadratic
Mendelsohn, et al. (2010)	Mexico	Ricardian	Farm	Land Value	Temperature Precipitation	Soil, socioeconomic and topography	Linear	Quadratic
Nhemachena, et al. (2010)	Africa	Ricardian	Farm	Land Value	Temperature Precipitation	Soil and socioeconomic	Linear	Quadratic
Thapa and Joshi (2010)	Nepal	Ricardian	Farm	Land Value	Temperature Precipitation	Soil and socioeconomic	Linear	Quadratic
Deschenes and Kolstad (2011)	California, US	Ricardian	Aggregate	Land Value	Temperature (Degree days or seasonal average) Precipitation	Soil and socioeconomic	Linear	Quadratic
Kurukulasuriya, et al. (2011)	Africa	Structural Ricardian	Farm	Land Value	Temperature Precipitation	Soil, socioeconomic and technology	Linear	Quadratic

Massetti and Mendelsohn (2011)	US	Structural Ricardian	Farm	Land Value	Temperature Precipitation	Soil, socioeconomic, hydrology and topography	Linear	Quadratic
Ajetomobi, et al. (2011)	Nigeria	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, socioeconomic and household characteristics	Linear	Quadratic
Fezzi and Bateman (2012)	Wales and United Kingdom	Structural Ricardian	Farm	Land Value	Monthly or Seasonal Average Degree days Precipitation	Soil and socioeconomic	Smoothing function	Linear
Di Falco, et al. (2012)	Ethiopia	Structural Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, topography, socioeconomic and household characteristics	Linear Log-linear Box–Cox	Quadratic
De Salvo, et al. (2013)	Italy	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, topography and socioeconomic	Linear Log-linear Box–Cox	Quadratic
Massetti, et al. (2013)	Brazil	Structural Ricardian	Farm	Land Value	Temperature Precipitation	Soil, topography and socioeconomic	Linear	Quadratic

Di Falco and Veronesi (2013)	Ethiopia	Structural Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, topography, hydrology, socioeconomic and household characteristics	Linear Log-linear Box–Cox	Quadratic
Mikémina (2013)	Togo	Ricardian	Farm	Net Revenue	Temperature Precipitation	Socioeconomic	Linear	Quadratic
Chen, et al. (2013)	China	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, topography and socioeconomic	Linear	Quadratic
Massetti, et al. (2014)	US	Ricardian	Farm	Land Value	Temperature (Degree days and Growing season average) Precipitation	Soil, topography, hydrology and socioeconomic	Linear	Quadratic
Mendelsohn (2014)	Asia	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, socioeconomic and technology	Linear	Quadratic
Chatzopoulos and Lippert (2015)	Germany	Structural Ricardian	Farm	Land rental price	Temperature Precipitation	Soil, topography and socioeconomic	Linear	Quadratic
Fezzi and Bateman (2015)	Great Britain	Structural Ricardian	Farm	Land Value	Degree days (main growing season average)	Soil, topography and	Semi-parametric	Quadratic

					Monthly or Seasonal average Precipitation	socioeconomic		
Luis, et al. (2015)	Mexico	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, topography, socioeconomic and technology	Linear	Quadratic
Massetti and Mendelsohn (2015)	US	Fixed effect	Farm	Land Value	Temperature Precipitation	Soil, topography and socioeconomic	Linear	Quadratic
Closset, et al. (2015)	Tajikistan	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, hydrology and socioeconomic	Linear	Quadratic
Bello and Maman (2015)	Niger	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil and socioeconomic	Linear	Quadratic
Coster and Adeoti (2015)	Nigeria	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil and socioeconomic	Linear	Quadratic
Moniruzzaman (2015)	Bangladesh	Structural Ricardian	Farm	Net Revenue	Temperature Precipitation	Socioeconomic	Linear	Quadratic
Massetti, et al. (2016)	US	Ricardian	Farm	Land Value	Temperature (Degree days and Growing season average) Precipitation	Soil, topography and socioeconomic	Linear	Quadratic

Seo (2016)	Latin America	Ricardian Spatial Ricardian	Farm	Land Value	Temperature Precipitation	Topography, soil and household	Linear	Quadratic
Vanschoenwinkel, et al. (2016)	Europe	Ricardian	Farm	Land Value	Temperature Precipitation	Topography, socioeconomic and soil	Linear	Quadratic
Dall'Erba and Domínguez (2016)	US	Ricardian Spatial Autocorrelation	Farm	Land Value	Temperature Precipitation	Socioeconomic and soil	Linear	Quadratic
Onyekuru and Marchant (2016)	Nigeria	Ricardian	Farm	Net Revenue	Temperature Precipitation	Household, socioeconomic, hydrology and soil	Linear	Quadratic
Bawayelaazaa Nyuor, et al. (2016)	Ghana	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, household and socioeconomic	Linear	Quadratic
Abidoye, et al. (2017)	South-East Asia	Ricardian Structural Ricardian	Farm	Net Revenue	Temperature (Growing season average) Precipitation	Soil and socioeconomic	Linear	Quadratic
Abidoye, et al. (2017)	Bangladesh, Sri Lanka, Thailand, and Vietnam	Ricardian Structural Ricardian	Farm	Net Revenue	Temperature (Growing season average) Precipitation	Socioeconomic	Linear	Quadratic

Passel, et al. (2017)	Europe	Ricardian	Farm	Land Value	Temperature Precipitation	Soil, socioeconomic and topography	Linear	Quadratic
Batsuuri and Wang (2017)	Mongolia	Ricardian	Aggregate Farm	Net Revenue	Temperature Precipitation	Socioeconomic and topography	Linear	Quadratic
Samrat and Alok (2017)	Nepal	Spatial Ricardian	Farm	Land Value	Temperature Precipitation	Socioeconomic	Linear	Quadratic
Bozzola, et al. (2018)	Italy	Ricardian	Farm	Land Value	Temperature Precipitation	Socioeconomic and soil	Log-linear	Quadratic
Severen, et al. (2018)	US	Fixed effect	Farm	Land Value	Temperature Precipitation	Socioeconomic	Linear	Quadratic
Trinh (2018)	Vietnam	Structural Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, household, socioeconomic and topography	Linear	Quadratic
Vanschoenwinkel and Van Passel (2018)	Europe	Ricardian	Farm	Land Value	Temperature Precipitation	Soil, topography and socioeconomic	Linear	Quadratic
Hossain, et al. (2018)	Bangladesh	Ricardian	Farm	Net Revenue	Temperature Precipitation	Household, socioeconomic and soil	Linear	Quadratic
Fonta, et al. (2018)	Nigeria	Ricardian	Farm	Net Revenue	Temperature Precipitation	Soil, topography, socioeconomic and household	Linear	Quadratic

Quaye, et al. (2018)	US	Ricardian	Farm	Land Value	Temperature Precipitation	Soil, topography and socioeconomic	Linear	Quadratic
Vaitkeviciute, et al. (2019)	Europe	Ricardian Spatial Panel Data Model	Farm	Land Value	Temperature Precipitation	Soil and socioeconomic	Linear	Quadratic
Sadiq, et al. (2019)	Pakistan	Ricardian Spatial Autocorrelation	Farm	Net Revenue	Temperature Precipitation	Household and socioeconomic	Linear	Quadratic
ASCIUTO, et al. (2019)	Sicily, Italy	Ricardian	Farm	Net Revenue	Temperature Precipitation	Slope and socioeconomic	Linear	Quadratic
Etwire, et al. (2019)	Ghana	Structural Ricardian	Farm	Net Revenue	Temperature Precipitation	Household and soil	Linear	Quadratic
DePaula (2020)	Brazil	Ricardian quantile	Farm	Land Value	Temperature Precipitation	Soil and socioeconomic	Linear	Quadratic
Hossain, et al. (2020)	Bangladesh	Standard Ricardian	Farm	Net Revenue	Temperature Precipitation	Household, soil and socioeconomic	Linear	Quadratic
Massetti and Mendelsohn (2020)	US	Ricardian	Farm	Land Value	Temperature bins (seasonal average)	Topography, soil and socioeconomic	Linear	Quadratic
Ortiz-Bobea (2020)	US	Ricardian	Farm	Cash Land rents	Temperature (Degree-days) Precipitation	Soil, socioeconomic, topography	Linear	Quadratic

Jawid (2020)	Afghanistan	Ricardian	Farm	Net Revenue	Temperature Precipitation	Topography and household	Linear	Quadratic
Tun Oo, et al. (2020)	Myanmar	Ricardian	Farm	Net Revenue	Temperature Precipitation	Household and socio economic	Linear	Quadratic
Feng, et al. (2021)	China	Structural Ricardian	Farm	Net Revenue	Temperature Precipitation	Household, socioeconomic and topography	Linear	Quadratic
Sultan (2021)	Mauritius	Ricardian	Farm	Net Revenue	Temperature Precipitation	Household and topography	Linear	Quadratic
Baylie and Fogarassy (2021)	Ethiopia	Ricardian Fixed-Effect	Farm	Net Revenue	Temperature Precipitation	Household and socioeconomic	Linear	Quadratic
Ali, et al. (2021)	Pakistan	Ricardian	Farm	Net Revenue	Temperature Precipitation	Household, socioeconomic and soil	Linear	Quadratic
Ojo and Baiyegunhi (2021)	Nigeria	Structural Ricardian	Farm	Net Revenue	Temperature Precipitation	Household and socioeconomic	Linear	Quadratic
Luh and Chang (2021)	Taiwan	Structural Ricardian	Farm	Net Revenue	Temperature Precipitation	Household characteristics and socioeconomic	Linear	Quadratic
Nguyen and Scrimgeour (2022)	Vietnam	Structural Ricardian	Farm	Net Revenue	Temperature Precipitation	Household, socioeconomic and topography	Linear	Quadratic

References

Abidoye, B.O., P. Kurukulasuriya, B. Reed, and R. Mendelsohn. 2017. "Structural Ricardian analysis of south-east Asian agriculture." *Climate Change Economics* 8:1740005.

Abidoye, B.O., R. Mendelsohn, S. Ahmed, S. Amanullah, C. Chasidpon, L. Baker, R. Dobias, B. Ghosh, L. Gunaratne, and M.M. Hedeyetullah. 2017. "South-East Asian Ricardian studies: Bangladesh, Sri Lanka, Thailand, and Vietnam." *Climate Change Economics* 8:1740004.

Adams, R.M., B.A. McCarl, D.J. Dudek, and J.D. Glyer. 1988. "Implications of global climate change for western agriculture." *Western Journal of Agricultural Economics*:348-356.

Adams, R.M., B.A. McCarl, K. Segerson, C. Rosenzweig, K.J. Bryant, B.L. Dixon, R. Conner, R.E. Evenson, and D. Ojima. 1999. "The economic effects of climate change on US agriculture." *The impact of climate change on the United States Economy*:18-54.

Adams, R.M., C. Rosenzweig, R.M. Peart, J.T. Ritchie, B.A. McCarl, J.D. Glyer, R.B. Curry, J.W. Jones, K.J. Boote, and L.H. Allen. 1990. "Global climate change and US agriculture." *Nature* 345:219-224.

Ajetomobi, J., A. Abiodun, and R. Hassan. 2011. "Impacts of climate change on rice agriculture in Nigeria." *Tropical and subtropical agroecosystems* 14:613-622.

Ali, U., J. Wang, A. Ullah, A. Ishtiaque, T. Javed, and Z. Nurgazina. 2021. "The impact of climate change on the economic perspectives of crop farming in Pakistan: Using the ricardian model." *Journal of Cleaner Production* 308:127219.

ASCIUTO, A., C.P. Di Franco, C. Zinnanti, E. SCHIMMENTI, G. Schifani, G. MIGLIORE, and V. BORSELLINO. 2019. "A Ricardian analysis of the impact of climate change on permanent crops in a Mediterranean region." *New Medit: Mediterranean Journal of Economics, Agriculture and Environment= Revue Méditerranéenne d'Economie Agriculture et Environment* 18.

Auffhammer, M. 2018. "Quantifying economic damages from climate change." *Journal of Economic Perspectives* 32:33-52.

Auffhammer, M., and W. Schlenker. 2014. "Empirical studies on agricultural impacts and adaptation." *Energy Economics* 46:555-561.

Batsuuri, T., and J. Wang. 2017. "The impacts of climate change on Nomadic livestock husbandry in Mongolia." *Climate Change Economics* 8:1740003.

Bawayelaazaa Nyuor, A., E. Donkor, R. Aidoo, S. Saaka Buah, J.B. Naab, S.K. Nutsugah, J. Bayala, and R. Zougmoré. 2016. "Economic impacts of climate change on cereal production: implications for sustainable agriculture in Northern Ghana." *Sustainability* 8:724.

Baylie, M.M., and C. Fogarassy. 2021. "Examining the Economic Impacts of Climate Change on Net Crop Income in the Ethiopian Nile Basin: A Ricardian Fixed Effect Approach." *Sustainability* 13:7243.

Bello, G.H.M., and M.N.M. Maman. 2015. "A ricardian analysis of the impact of temperature and rainfall variability on ag-riculture in dosso and maradi regions of niger republic." *Agricultural Sciences* 6:724.

Benhin, J.K. 2008. "South African crop farming and climate change: An economic assessment of impacts." *Global environmental change* 18:666-678.

Blanc, E., and J. Reilly. 2017. "Approaches to assessing climate change impacts on agriculture: an overview of the debate." *Review of Environmental Economics and Policy*.

Bozzola, M., E. Massetti, R. Mendelsohn, and F. Capitanio. 2018. "A Ricardian analysis of the impact of climate change on Italian agriculture." *European Review of Agricultural Economics* 45:57-79.

Burke, M., and K. Emerick. 2016. "Adaptation to climate change: Evidence from US agriculture." *American Economic Journal: Economic Policy* 8:106-140.

Chatzopoulos, T., and C. Lippert. 2015. "Adaptation and climate change impacts: a structural Ricardian analysis of farm types in Germany." *Journal of Agricultural Economics* 66:537-554.

Chen, Y., Z. Wu, K. Okamoto, X. Han, G. Ma, H. Chien, and J. Zhao. 2013. "The impacts of climate change on crops in China: A Ricardian analysis." *Global and Planetary change* 104:61-74.

Cline, W.R. 1996. "The impact of global warming of agriculture: comment." *The American economic review* 86:1309-1311.

Closset, M., B.B.B. Dhehibi, and A. Aw-Hassan. 2015. "Measuring the economic impact of climate change on agriculture: a Ricardian analysis of farmlands in Tajikistan." *Climate and Development* 7:454-468.

Coster, A., and A. Adeoti. 2015. "Economic effects of climate change on maize production and farmers' adaptation strategies in Nigeria: a Ricardian approach." *Journal of Agricultural Science* 7:67.

Dall'Erba, S., and F. Domínguez. 2016. "The impact of climate change on agriculture in the Southwestern United States: The Ricardian approach revisited." *Spatial Economic Analysis* 11:46-66.

Darwin, R. 1999. "The impact of global warming on agriculture: A Ricardian analysis: Comment." *American economic review* 89:1049-1052.

De Salvo, M., R. Raffaelli, and R. Moser. 2013. "The impact of climate change on permanent crops in an Alpine region: A Ricardian analysis." *Agricultural systems* 118:23-32.

Dell, M., B.F. Jones, and B.A. Olken. 2014. "What do we learn from the weather? The new climate-economy literature." *Journal of Economic Literature* 52:740-798.

DePaula, G. 2020. "The distributional effect of climate change on agriculture: Evidence from a Ricardian quantile analysis of Brazilian census data." *Journal of Environmental Economics and Management* 104:102378.

Deressa, T., R. Hassan, and D. Poonyth. 2005. "Measuring the impact of climate change on South African agriculture: the case of sugarcane growing regions." *Agrekon* 44:524-542.

Deressa, T.T. 2007. "Measuring the economic impact of climate change on Ethiopian agriculture: Ricardian approach." *World Bank Policy Research Working Paper*.

Deschênes, O., and M. Greenstone. 2007. "The economic impacts of climate change: evidence from agricultural output and random fluctuations in weather." *American economic review* 97:354-385.

Deschenes, O., and C. Kolstad. 2011. "Economic impacts of climate change on California agriculture." *Climatic change* 109:365-386.

Di Falco, S. 2014. "Adaptation to climate change in Sub-Saharan agriculture: assessing the evidence and rethinking the drivers." *European Review of Agricultural Economics* 41:405-430.

Di Falco, S., and M. Veronesi. 2013. "How can African agriculture adapt to climate change? A counterfactual analysis from Ethiopia." *Land economics* 89:743-766.

Di Falco, S., M. Yesuf, G. Kohlin, and C. Ringler. 2012. "Estimating the impact of climate change on agriculture in low-income countries: Household level evidence from the Nile Basin, Ethiopia." *Environmental and Resource Economics* 52:457-478.

Dinar, A., R. Mendelsohn, R. Evenson, J. Parikh, A. Sanghi, K.S.K. Kumar, J. McKinsey, and S. Lonergen. "Measuring the Impact of CLimate Change on Indian Agriculture." World Bank - Technical Papers.

Eid, H.M., S.M. El-Marsafawy, and S.A. Ouda. 2007. "Assessing the economic impacts of climate change on agriculture in Egypt: a Ricardian approach." *World Bank Policy Research Working Paper*.

Etwire, P.M., D. Fielding, and V. Kahui. 2019. "Climate change, crop selection and agricultural revenue in Ghana: a structural Ricardian analysis." *Journal of Agricultural Economics* 70:488-506.

Feng, X., H. Qiu, J. Pan, and J. Tang. 2021. "The impact of climate change on livestock production in pastoral areas of China." *Science of the Total Environment* 770:144838.

Fezzi, C., and I. Bateman. 2015. "The impact of climate change on agriculture: nonlinear effects and aggregation bias in Ricardian models of farmland values." *Journal of the Association of Environmental and Resource Economists* 2:57-92.

---. "Non-linear effects and aggregation bias in Ricardian models of climate change." CSERGE working paper.

Fisher, A.C., and W.M. Hanemann. 1998. "The impact of global warming on agriculture: Rethinking the Ricardian approach."

Fisher, A.C., W.M. Hanemann, M.J. Roberts, and W. Schlenker. 2012. "The economic impacts of climate change: evidence from agricultural output and random fluctuations in weather: comment." *American economic review* 102:3749-3760.

Fleischer, A., I. Lichtman, and R. Mendelsohn. 2008. "Climate change, irrigation, and Israeli agriculture: Will warming be harmful?" *Ecological economics* 65:508-515.

Fonta, W.M., A.M. Kedir, A.Y. Bossa, K.M. Greenough, B.M. Sylla, and E.T. Ayuk. 2018. "A Ricardian valuation of the impact of climate change on Nigerian cocoa production: Insight for adaptation policy." *International Journal of Climate Change Strategies and Management*.

Gbetibouo, G.A., and R.M. Hassan. 2005. "Measuring the economic impact of climate change on major South African field crops: a Ricardian approach." *Global and Planetary change* 47:143-152.

Gunaratne, L. (2022) "Economic Analysis of Climate Change Adaptations in Agriculture." In *Agricultural Policy Analysis.* Springer, pp. 423-435.

Hossain, M.S., M. Arshad, L. Qian, H. Kächele, I. Khan, M.D.I. Islam, and M.G. Mahboob. 2020. "Climate change impacts on farmland value in Bangladesh." *Ecological indicators* 112:106181.

Hossain, M.S., L. Qian, M. Arshad, S. Shahid, S. Fahad, and J. Akhter. 2018. "Climate change and crop farming in Bangladesh: an analysis of economic impacts." *International Journal of Climate Change Strategies and Management* 11:424-440.

Jain, S. 2007. "An empirical economic assessment of impacts of climate change on agriculture in Zambia." *World Bank Policy Research Working Paper*.

Jawid, A. 2020. "A Ricardian analysis of the economic impact of climate change on agriculture: Evidence from the farms in the central highlands of Afghanistan." *Journal of Asian Economics* 67:101177.

Kabubo-mariara, J. 2008. "Climate Change Adaptation and Livestock Activity Choices in Kenya. An Economic Analysis Natural Resources."

Kabubo-Mariara, J., and F.K. Karanja. 2007. "The economic impact of climate change on Kenyan crop agriculture: A Ricardian approach." *Global and Planetary change* 57:319-330.

Kelly, D.L., C.D. Kolstad, and G.T. Mitchell. 2005. "Adjustment costs from environmental change." *Journal of Environmental Economics and Management* 50:468-495.

Kolstad, C.D., and F.C. Moore. 2020. "Estimating the economic impacts of climate change using weather observations." *Review of Environmental Economics and Policy*.

Kovacs, K., and S. Rider. 2022. "Estimating the Demand for In-situ Groundwater for Climate Resilience: The Case of the Mississippi River Alluvial Aquifer in Arkansas." *NBER Chapters*.

Kumar, K.K. 2011. "Climate sensitivity of Indian agriculture: do spatial effects matter?" *Cambridge Journal of Regions, Economy and Society* 4:221-235.

Kumar, K.K., and J. Parikh. 2001. "Indian agriculture and climate sensitivity." *Global environmental change* 11:147-154.

Kurukulasuriya, P. 2007. *A Ricardian analysis of the impact of climate change on African cropland*: World Bank Publications.

Kurukulasuriya, P., and M.I. Ajwad. 2007. "Application of the Ricardian technique to estimate the impact of climate change on smallholder farming in Sri Lanka." *Climatic change* 81:39-59.

Kurukulasuriya, P., N. Kala, and R. Mendelsohn. 2011. "Adaptation and climate change impacts: a structural Ricardian model of irrigation and farm income in Africa." *Climate Change Economics* 2:149-174.

Kurukulasuriya, P., and R. Mendelsohn. 2008. "Crop switching as a strategy for adapting to climate change." *African Journal of Agricultural and Resource Economics* 2:105-126.

Kurukulasuriya, P., R. Mendelsohn, R. Hassan, J. Benhin, T. Deressa, M. Diop, H.M. Eid, K.Y. Fosu, G. Gbetibouo, and S. Jain. 2006. "Will African agriculture survive climate change?" *The World Bank Economic Review* 20:367-388.

Kurukulasuriya, P., and R. Mendelsohn. 2007. "Endogenous irrigation: The impact of climate change on farmers in Africa." *World Bank Policy Research Working Paper*.

---. 2008. "How will climate change shift agro-ecological zones and impact African agriculture?" *World Bank Policy Research Working Paper*.

Lang, G. 2007. "Where are Germany's gains from Kyoto? Estimating the effects of global warming on agriculture." *Climatic change* 84:423-439.

Lippert, C., T. Krimly, and J. Aurbacher. 2009. "A Ricardian analysis of the impact of climate change on agriculture in Germany." *Climatic change* 97:593-610.

Liu, H., X. Li, G. Fischer, and L. Sun. 2004. "Study on the impacts of climate change on China's agriculture." *Climatic change* 65:125-148.

Luh, Y.-H., and Y.-C. Chang. 2021. "Effect of climate change on staple food production: empirical evidence from a structural ricardian analysis." *Agronomy* 11:369.

Luis, M.G., R. Orlando, and E.A. Jos. 2015. "Climate change, irrigation and agricultural activities in Mexico: A Ricardian analysis with panel data." *Journal of Development and Agricultural Economics* 7:262-273.

Maddison, D. 2000. "A hedonic analysis of agricultural land prices in England and Wales." *European Review of Agricultural Economics* 27:519-532.

Mano, R., and C. Nhemachena. 2007. "Assessment of the economic impacts of climate change on agriculture in Zimbabwe: A Ricardian approach." *World Bank Policy Research Working Paper*.

Maria, D.S., B. Diego, and S. Giovanni. 2014. "The Ricardian analysis twenty years after the original model: Evolution, unresolved issues and empirical problems." *Journal of Development and Agricultural Economics* 6:124-131.

Massetti, E., and R. Mendelsohn. 2011. "Estimating Ricardian models with panel data." *Climate Change Economics* 2:301-319.

---. 2015. "How do heat waves, cold waves, droughts, hail and tornadoes affect US agriculture." *CMCC Research Paper (RP0271)*.

---. 2020. "Temperature thresholds and the effect of warming on American farmland value." *Climatic change* 161:601-615.

Massetti, E., R. Mendelsohn, and S. Chonabayashi. 2016. "How well do degree days over the growing season capture the effect of climate on farmland values?" *Energy Economics* 60:144-150.

Massetti, E., R. Mendelsohn, and S. Chonabayashi. 2014. "Using degree days to value farmland." *Available at SSRN 2550177*.

Massetti, E., R.d.C. Nascimento Guiducci, A. Fortes de Oliveira, and R. Mendelsohn. 2013. "The impact of climate change on the Brazilian agriculture: a Ricardian study at microregion level." *The Impact of Climate Change on the Brazilian Agriculture: A Ricardian Study at Microregion Level (December 2013). CMCC Research Paper*.

Mendelsohn, R. 2014. "The impact of climate change on agriculture in Asia." *Journal of Integrative Agriculture* 13:660-665.

Mendelsohn, R., J. Arellano-Gonzalez, and P. Christensen. 2010. "A Ricardian analysis of Mexican farms." *Environment and development economics* 15:153-171.

Mendelsohn, R., and A. Dinar. 1999. "Climate change, agriculture, and developing countries: does adaptation matter?" *The World Bank Research Observer* 14:277-293.

---. 2003. "Climate, water, and agriculture." *Land economics* 79:328-341.

Mendelsohn, R., A. Dinar, and A. Sanghi. 2001. "The effect of development on the climate sensitivity of agriculture." *Environment and development economics* 6:85-101.

Mendelsohn, R., A. Dinar, and L. Williams. 2006. "The distributional impact of climate change on rich and poor countries." *Environment and development economics* 11:159-178.

Mendelsohn, R., P. Kurukulasuriya, A. Basist, F. Kogan, and C. Williams. 2007. "Climate analysis with satellite versus weather station data." *Climatic change* 81:71-83.

Mendelsohn, R., W. Nordhaus, and D. Shaw. 1996. "Climate impacts on aggregate farm value: accounting for adaptation." *Agricultural and forest meteorology* 80:55-66.

Mendelsohn, R., and W.D. Nordhaus. 1999. "The impact of global warming on agriculture: A Ricardian analysis: Reply." *American economic review* 89:1053-1055.

Mendelsohn, R., W.D. Nordhaus, and D. Shaw. 1994. "The impact of global warming on agriculture: a Ricardian analysis." *The American economic review*:753-771.

Mendelsohn, R., and M. Reinsborough. 2007. "A Ricardian analysis of US and Canadian farmland." *Climatic change* 81:9-17.

Mendelsohn, R., and S.N. Seo. 2007. "A structural ricardian analysis of climate change impacts and adaptations in African agriculture."

Mendelsohn, R., and A. Dinar. 2009. *Climate change and agriculture: an economic analysis of global impacts, adaptation and distributional effects*: Edward Elgar Publishing.

Mendelsohn, R., and E. Massetti. 2017. "The use of cross-sectional analysis to measure climate impacts on agriculture: theory and evidence." *Review of Environmental Economics and Policy*.

Mendelsohn, R., and S.N. Seo. 2007. "Changing farm types and irrigation as an adaptation to climate change in Latin American agriculture." *World Bank Policy Research Working Paper*.

Mikémina, P. 2013. "Climate change impact on Togo's agriculture performance: a ricardian analysis based on time series data." *Ethiopian Journal of Environmental Studies and Management* 6:390-397.

Molua, E.L. 2007. "The economic impact of climate change on agriculture in Cameroon." *World Bank Policy Research Working Paper*.

Moniruzzaman, S. 2015. "Crop choice as climate change adaptation: Evidence from Bangladesh." *Ecological economics* 118:90-98.

Nguyen, C.T., and F. Scrimgeour. 2022. "Measuring the impact of climate change on agriculture in Vietnam: A panel Ricardian analysis." *Agricultural Economics* 53:37-51.

Nhemachena, C., R. Hassan, and P. Kurukulasuriya. 2010. "Measuring the economic impact of climate change on African agricultural production systems." *Climate Change Economics* 1:33-55.

Nicita, L., G. Cucuzza, M. De Salvo, C. Prato, and G. Signorello. 2020. "Spatial effects and endogeneity in a Ricardian model of climate change: an application to a Mediterranean region." *Spatial Economic Analysis* 15:219-237.

Ojo, T., and L. Baiyegunhi. 2021. "Climate change perception and its impact on net farm income of smallholder rice farmers in South-West, Nigeria." *Journal of Cleaner Production* 310:127373.

Onyekuru, N.A., and R. Marchant. 2016. "Assessing the economic impact of climate change on forest resource use in Nigeria: A Ricardian approach." *Agricultural and forest meteorology* 220:10-20.

Ortiz-Bobea, A. 2020. "The role of nonfarm influences in Ricardian estimates of climate change impacts on US agriculture." *American Journal of Agricultural Economics* 102:934-959.

Passel, S.V., E. Massetti, and R. Mendelsohn. 2017. "A Ricardian analysis of the impact of climate change on European agriculture." *Environmental and Resource Economics* 67:725-760.

Quaye, F., D. Nadolnyak, and V. Hartarska. 2018. "Climate change impacts on farmland values in the Southeast United States." *Sustainability* 10:3426.

Quiggin, J., and J.K. Horowitz. 1999. "The impact of global warming on agriculture: A Ricardian analysis: Comment." *The American economic review* 89:1044.

Reinsborough, M.J. 2003. "A Ricardian model of climate change in Canada." *Canadian Journal of Economics/Revue canadienne d'économique* 36:21-40.

Rosenzweig, C., and M.L. Parry. 1994. "Potential impact of climate change on world food supply." *Nature* 367:133-138.

Sadiq, S., A. Saboor, A.Q. Mohsin, A. Khalid, and F. Tanveer. 2019. "Ricardian analysis of climate change–agriculture linkages in Pakistan." *Climate and Development* 11:679-686.

Samrat, B.K., and K.B. Alok. 2017. "Climate sensitivities and farmland values in Nepal: A spatial panel Ricardian approach." *Journal of Development and Agricultural Economics* 9:145-161.

Sanghi, A., and R. Mendelsohn. 2008. "The impacts of global warming on farmers in Brazil and India." *Global environmental change* 18:655-665.

Sanghi, A., R. Mendelsohn, and A. Dinar. 1998. "The climate sensitivity of Indian agriculture." *Measuring the impact of climate change on Indian agriculture*:69-139.

Schlenker, W., W.M. Hanemann, and A.C. Fisher. 2006. "The impact of global warming on US agriculture: an econometric analysis of optimal growing conditions." *Review of Economics and statistics* 88:113-125.

---. 2007. "Water availability, degree days, and the potential impact of climate change on irrigated agriculture in California." *Climatic change* 81:19-38.

---. 2005. "Will US agriculture really benefit from global warming? Accounting for irrigation in the hedonic approach." *American economic review* 95:395-406.

Seo, N., R. Mendelsohn, P. Kurukulasuriya, A. Dinar, and R.M. Hassan. 2008. "Differential adaptation strategies to climate change in African cropland by agro-ecological zones." *World Bank Policy Research Working Paper*.

Seo, S.-N.N., R. Mendelsohn, and M. Munasinghe. 2005. "Climate change and agriculture in Sri Lanka: a Ricardian valuation." *Environment and development economics* 10:581-596.

Seo, S.N. 2010. "A microeconometric analysis of adapting portfolios to climate change: adoption of agricultural systems in Latin America." *Applied Economic Perspectives and Policy* 32:489-514.

---. 2016. "Modeling farmer adaptations to climate change in South America: a micro-behavioral economic perspective." *Environmental and Ecological Statistics* 23:1-21.

Seo, S.N. 2008. *A structural Ricardian analysis of climate change impacts and adaptations in African agriculture*: World Bank Publications.

Seo, S.N., and R. Mendelsohn. 2008. "An analysis of crop choice: Adapting to climate change in South American farms." *Ecological economics* 67:109-116.

---. 2008. "Animal husbandry in Africa: climate change impacts and adaptations." *African Journal of Agricultural and Resource Economics* 2:65-82.

---. 2008. "Measuring impacts and adaptations to climate change: a structural Ricardian model of African livestock management 1." *Agricultural Economics* 38:151-165.

Seo, S.N., R. Mendelsohn, A. Dinar, R. Hassan, and P. Kurukulasuriya. 2009. "A Ricardian analysis of the distribution of climate change impacts on agriculture across agro-ecological zones in Africa." *Environmental and Resource Economics* 43:313-332.

Seo, S.N., and R. Mendelsohn. 2007. "An analysis of livestock choice: Adapting to climate change in Latin American farms." *World Bank Policy Research Working Paper*.

---. 2007. "Climate change impacts on animal husbandry in Africa: A Ricardian analysis." *World Bank Policy Research Working Paper*.

Seo, S.N., and R. Mendelsohn. 2007. *The impact of climate change on livestock management in Africa: a structural Ricardian analysis*: World Bank Publications.

---. 2007. *A Ricardian analysis of the impact of climate change on Latin American farms*: World Bank Publications.

Severen, C., C. Costello, and O. Deschenes. 2018. "A Forward-Looking Ricardian Approach: Do land markets capitalize climate change forecasts?" *Journal of Environmental Economics and Management* 89:235-254.

Sultan, R. (2021) "Economic Impacts of Climate Change on Agriculture: Insights from the Small Island Economy of Mauritius." In *Small Island Developing States.* Springer, pp. 137-158.

Thapa, S., and G.R. Joshi. 2010. "A Ricardian analysis of the climate change impact on Nepalese agriculture."

Trinh, T.A. 2018. "The impact of climate change on agriculture: findings from households in Vietnam." *Environmental and Resource Economics* 71:897-921.

Tun Oo, A., G. Van Huylenbroeck, and S. Speelman. 2020. "Measuring the economic impact of climate change on crop production in the dry zone of Myanmar: A Ricardian Approach." *Climate* 8:9.

Vaitkeviciute, J., R. Chakir, and S. Van Passel. 2019. "Climate variable choice in Ricardian studies of European agriculture." *Revue économique* 70:375-401.

Vanschoenwinkel, J., R. Mendelsohn, and S. Van Passel. 2016. "Do Western and Eastern Europe have the same agricultural climate response? Taking adaptive capacity into account." *Global environmental change* 41:74-87.

Vanschoenwinkel, J., and S. Van Passel. 2018. "Climate response of rainfed versus irrigated farms: the bias of farm heterogeneity in irrigation." *Climatic change* 147:225-234.

Wang, J., R. Mendelsohn, A. Dinar, J. Huang, S. Rozelle, and L. Zhang. 2009. "The impact of climate change on China's agriculture." *Agricultural Economics* 40:323-337.

Weber, M., and G. Hauer. 2003. "A regional analysis of climate change impacts on Canadian agriculture." *Canadian Public Policy/Analyse de Politiques*:163-180.

Wijaya, A. (2014) "Climate change, global warming and global inequity in developed and developing countries (Analytical perspective, Issue, Problem and Solution)." In *IOP Conference Series: Earth and Environmental Science.* IOP Publishing, pp. 012008.